Dip effect and surface barrier in single crystal $YBa_2Cu_3O_x$

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Abstract

We carefully measured the ac susceptibility for a $YBa_2Cu_3O_{6.993}$ single crystal at different dc fields and observed a giant dip effect. The ac susceptibility in lower dc fields signals the transition of flux pinning mechanism. Meanwhile, the hysteric behavior of ac susceptibility as the temperature goes down confirms that the solid-liquid phase transition of vortex matter takes place just below the dip temperature.

Key words: dip effect;surface barrier;$YBa_2Cu_3O_x$;

1. Introduction

In an ideal vortex matter system, one has seen a first-order melting transition. However, the surface barriers (SB) could depress the formation of the liquid-solid of vortex matter phase transition in high temperature superconductors (HTSC) [1-9]. In this paper, measurement was made of ac susceptibility (acs) as a function of temperature T and dc fields (H_{dc}) for $YBa_2Cu_3O_{6.993}$ single crystal. Dips and hysteric loops in acs curves were observed. The dip was weaken and finally disappeared as the applied field goes down, evidencing the transition of flux pinning mechanism. Meanwhile, hysteric acs appears just below the dip temperature as the temperature goes down, indicating that the behavior of a general solid phase takes place in vortex matter.

2. Experiment

The sample was a ultra-pure $YBa_2Cu_3O_{6.993}$ single crystal grown in a bulk BaZrO3 crucible. The chemical and structural characterization of this crystal confirmed that it had very low level of impurity elements and high degree of crystalline order. The sample is a perfect rectangle with dimensions $1.53 \times 1.28 \times 0.065 mm^3$, and the c axis along the shortest dimension. The bulk of the crystal is twin-free except a single twin boundary cutting the very tip of one of the Four Corners, forming a triangle, which has an area less than 0.12 percent of the total sample area.

Our experiment technique is the acs, both dc and ac magnetic fields are along the c-axis of the crystal. The acs data were extracted from the impedance data of the coil, measured by a two-phase lock-in amplifier.

3. Result and discussion

Fig.1 shows the experimental χ' as function of T and H_{dc} at a given ac amplitude hac and frequency f, where one can see clearly a dip (a sharp minimum of χ') effect DE. Here we define a "dip depth" of acs as $\chi'_{dip} = \chi'_{max} - \chi'_{min}$, χ'_{max} and χ'_{min} are maximum and minimum of acs respectively, and T_{min} as the temperature at which $\chi' = \chi'_{min}$. Fig.1 shows that the behavior of acs in the high field regime is quite different from that in the low field regime. In the formal regime, with the decreasing H_{dc} the dip depth c'dip gradually increases. However, when dc field further decreases the dip depth

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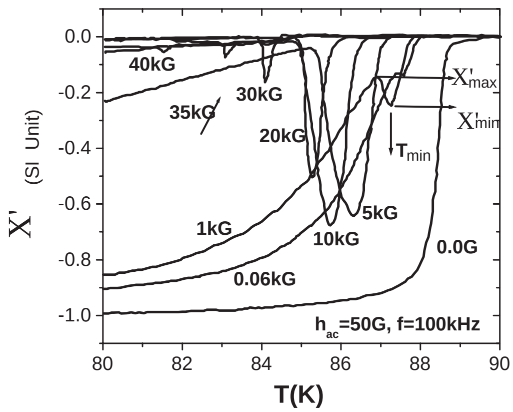

Fig. 1. Experimental $\chi'(T)$ curves under different dc fields $H_{dc}(H_{dc}//h_{ac}//c)$, showing the giant dip effect.

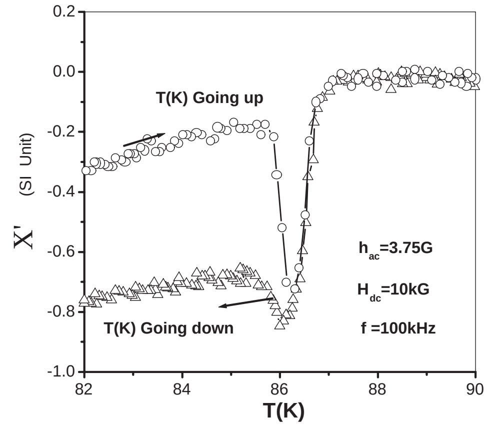

Fig. 2. Hysteric ac susceptibility evidencing a behavior of vortex solid that occurs just below the temperature T_{min} where the dip effect takes place. Whereas, the hysteresis disappears just above T_{min}.

c'dip turns to decrease, and finally the χ'_{dip} becomes too small to probe. Therefore, the dip is governed by a mechanism different from that of acs itself. This characteristic is explained in terms of the competition between SB and bulk pinning (BP). In the elevated temperatures and low field, SB is dominated which causes a sharp low field peak in a magnetic hysteric loop. Whereas at low temperatures and high fields the BP governs the hysteric magnetization loop and results in the second peak effect [5,10,11]. It has been pointed out that the vortex liquid-solid phase transition occurs just below the dip temperature [3], which is of curse a bulk phenomenon. The liquid is an equilibrium state without any hysteric magnetic behavior and the solid maybe in a non-equilibrium state that a historical behavior of magnetization maybe observed. Fig.2 shows the experimental acs curves with different 'history'. It is very clear that the hysteric acs takes place just below T_{min}, evidencing a behavior of vortex solid in low temperatures. Meanwhile, the hysteric magnetic behavior disappears at temperatures higher than T_{min}, and the ac susceptibility now is reversible one, showing the equilibrium vortex liquid characteristics. Fig.1 and Fig2 clearly show that T_{min} is dependent on the applied field H_{dc}, implying the solid-liquid phase transition line is a H_{dc}-T curve. This is a strong confirmation that the dip of ac susceptibility of our sample indicates the vortex liquid-solid phase transition.

In summary, we have shown that the dip is the signal of the vortex liquid-solid phase transition. Furthermore, the ac susceptibility measurement in different T and H_{dc} is a powerful technique probing directly the vortex liquid-solid phase transition just as the measurement of R(T,H_{dc})

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